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INDIVIDUALIZED SYSTEMS OF INSTRUCTION

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The techniques and effectiveness of systems for adjusting the pace, content, sequence, and/or style of instruction to fit the needs of individual learners are briefly reviewed. These systems are all designed to function within group instructional settings. They may be separated into print-oriented approaches (Programmed Instruction, Personalized System of Instruction, Audio-Tutorial Approach, and Individually Guided Education) and computer-oriented approaches (Individually Prescribed Instruction, Adaptive Learning Environments Model, Program for Learning in Accordance with Needs, the Strands Approach, Optimization of Instruction, and Intelligent Computer-Assisted Instruction). The primary task of these and similar systems is to replace the two standard deviations of achievement that may be lost by grouping students for instruction rather than providing a single teacher for each student in one-on-one, individualized instructional settings. Difficulty in accomplishing this task appears to lie primarily with the costs and increased workload that individualization requires.

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PREFACE

This work was performed in support of a general assessment of interactive courseware technologies for Defense training (IDA Task T-L2-883). These technologies can individualize education and training within our contemporary institutions of instruction, which focus on students as groups rather than as individuals. This document is intended to provide some perspective on the instructional capabilities of interactive courseware technologies by briefly reviewing what is known about individualizing systems of instruction used in settings outside of Defense training.

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ABSTRACT

The techniques and effectiveness of systems for adjusting the pace, content, sequence, and/or style of instruction to fit the needs of individual learners are briefly reviewed. These systems are all designed to function within group instructional settings. They may be separated into print-oriented approaches (Programmed Instruction, Personalized System of Instruction, Audio-Tutorial Approach, and Individually Guided Education) and computer-oriented approaches (Individually Prescribed Instruction, Adaptive Learning Environments Model, Program for Learning in Accordance with Needs, the Strands Approach, Optimization of Instruction, and Intelligent Computer-Assisted Instruction). The primary task of these and similar systems is to replace the two standard deviations of achievement that may be lost by grouping students for instruction rather than providing a single teacher for each student in one-on-one, individualized instructional settings. Difficulty in accomplishing this task appears to lie primarily with the costs and increased workload that individualization requires.

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I. INTRODUCTION

Instruction is individualized to the extent that it adjusts to differences in learners. Instructional systems combine organized collections of subject matter content with procedures and rules for presenting the content to bring about learning outcomes. In individualized systems of instruction, these procedures and rules adjust the pace, content, sequence, and/or style of instruction to the needs of individual learners.

Individualization of *pace* controls the rate at which individual learners progress through instructional content. It may be implemented in either or both of two ways. First, pace may be individualized by allowing learners to proceed as rapidly as they can or as slowly as they wish through a set of instructional items. Second, different numbers of items may be presented to different learners. This usually occurs when the items are generated by computer or the instruction involves simulation of a device or situation, but it may also occur when items are repeated or sampled from a fixed quantity. When different numbers of items are presented, pace may be further individualized through the rate with which new instructional content or levels of difficulty are introduced. Individualization of pace is so common that it is frequently, although incorrectly, viewed as synonymous with individualization of instruction.

Individualization of *content* is usually implemented in a diagnostic-prescriptive fashion. The learner's knowledge and skills are assessed prior to initiating work in a component of instruction which may range in scope from the entire program of instruction, to a chapter-length unit, to an individual item. Based on the results of the assessment, content is diagnostically adjusted to the learners' needs by prescribing that they skip the component entirely, study remedial material before working on it, or begin work in one or more 'tracks' within the component itself. In some implementations there is no practical distinction between assessment and instruction. The learner starts receiving instruction, and rules and procedures built into the system adjust the content and its presentation to accord with the learner's observed performance and estimated knowledge.

Individualization of *sequence* may take place at two levels. At a macro level it concerns the order of topics addressed by the instruction. Implementations at this level may involve learner control in which individual learners determine the sequence of topics

for themselves. Alternatively, this sequence may be determined in conference(s) between the learner and a teacher or other system administrator, or it may be determined solely by established procedure or algorithm. At a micro level, individualization of sequence determines the order in which items are presented. Applications at this level may simply present items in an arbitrary or random order. In these cases, the sequencing of items may be unique for each learner, but it is not tailored to their individual needs.

The manner in which different learners perceive, acquire, retain, and retrieve information may differ. These differences are usually called cognitive styles, and instructional systems that try to adjust to these differences are said to provide individualization of *style*. In practice, individualization of style usually involves adjustments in the modes or formats of presentation. For instance, instructional content may be presented using audio alone, printed text alone, text and graphics, or some other mode of presentation that is consonant with the cognitive style of the learner. Individualization of style is less well established as a useful approach than individualization of pace, content, and sequence. It may be less expensive and more effective for learners to adjust their style(s) to instruction than it is for instruction to adjust its style to learners, but research is needed to settle the issue. Federico and Landis (1984) and Brent (1990) summarize much of the research on cognitive style and report data suggesting that individualization of style is beneficial to learners but that the extent of these benefits depends on the instructional content and objectives.

II. BACKGROUND AND APPROACHES

Individualization of instruction has been viewed as a key component of instructional effectiveness since at least the fourth century B.C. (Corno and Snow, 1986). Kulik (1982), Wang and Lindvall (1984), and Reiser (1987) have reviewed the many individualized instructional systems that were in general use in the early 1980s and the history of research and events that led to them.

Current worldwide use of group instruction, which began only in the mid-1800s, has made mass education and training economically and administratively feasible. However, it has been accomplished through loss of the individualized tailoring of instruction that is provided by one instructor working with one learner. Bloom (1984) characterized this issue as the "2-sigma problem." He found that when instructional time is held constant, students in a conventional classroom with about 30 students and one teacher score about two standard deviations lower than students given individual tutoring. He defined the challenge for group instruction as one of recapturing the two standard deviations of achievement lost by grouping. Individualized systems of instruction may be viewed as attempts to recapture the power of individualized instruction without the encumbrance of its expense.

A. CONTRIBUTIONS OF TECHNOLOGY

The most significant contribution of technology to instruction may have occurred in the mid-1400s with Johannes Gutenberg's development of movable metallic type and printed books. These developments made effective instructional content inexpensively available to large numbers of people. A second significant contribution of technology to individualized instruction occurred in the mid-1900s with the development of stored-program computers. Computers made not just the content but also the interactions of effective instruction inexpensively available to large numbers of people.

Computers implement the rules and procedures for presenting instructional content that are key to individualization of instruction. However, "computer-based instruction" is too diffuse a term to describe any particular system or approach to instruction, as Clark (1983) has taken pains to remind us. It does not by itself represent an approach or

identifiable, coherent system for individualizing instruction. It is fundamentally a tool, albeit a powerful one.

Hypermedia capabilities controlled by computer, such as those of interactive videodisc, CD-ROM, and other multimedia systems broaden even more the promise of computer capabilities for the development of individualized systems of instruction. These approaches usually key on large-scale associativity in storing and retrieving information. Associativity, as Vannevar Bush (1945) emphasized, is not simply selection or indexing, which must proceed by examining every member of a large set of items and selecting those with specified characteristics. Instead, it mimics an individual's "association of thoughts in accordance with some intricate web of trails carried by the cells of the brain" (p. 106).

Hypermedia systems consist of a database of information in which all media for storage and presentation may be included, a set of links between all semantically associated elements in the database allowing rapid access and movement through it, and a consistent user interface for interactions (Conklin, 1987). Individualization of pace, content, sequence, and style may be combined through the use of hypermedia systems to a degree that is unimaginable without them.

B. CONTRIBUTIONS OF COGNITIVE PSYCHOLOGY

Every instructional program represents a view of how people perceive, think, and learn. It is not surprising to find that the shift in general theories of learning from the fairly strict logical positivism of behaviorism to what we now call cognitive psychology is reflected in our systems of instruction.

The keynote of current notions on cognitive psychology may have been struck by Ulric Neisser (1967) who stated, "The central assertion is that seeing, hearing, and remembering are all acts of *construction*, which may make more or less use of stimulus information depending on circumstances." (p. 10--the italics are Neisser's). Human cognition is, then, viewed as an overwhelmingly constructive process. Recall is not just retrieval of items from memory, but their reconstruction from more primitive cues. Perceivers and learners are not viewed as blank slates, passively recording bits of information transmitted to them over channels, but as active participants who use the fragmentary cues permitted them by their sensory receptors to construct, verify, and modify their own cognitive simulations of the outside world.

In this way, cognitive psychology calls into question the view of instruction as straightforward information transmission. Instruction provides cues that learners use to construct models of the subject matter. It creates environments in which students are encouraged to construct and modify their own models of the world. In this sense, all learning is both individualized and active. Systems intended to bring about learning, systems of instruction, differ only in the extent to which they assist learning by assuming the burden of individualization for the student.

The following discussion considers print-oriented and computer-oriented systems of individualized instruction. Print-oriented systems emphasize the use of paper-based printed materials. Computer-oriented systems attempt to capitalize on the promise of computer technology. Both types of systems may use audiovisual materials, computer-oriented systems may use printed materials, and the differences between the two primarily concern the amount of work performed by computers.

III. INDIVIDUALIZED INSTRUCTION: PRINT-ORIENTED APPROACHES

Most print-oriented approaches divide instructional content into units of instruction. Then, for each unit, they provide a preassessment of the learner, an individualized prescription of instruction content and presentation based on the preassessment, the instruction itself, and postassessment(s) on which the learner must display criterion levels of knowledge and/or performance before progressing to the next unit of instruction.

A. PROGRAMMED INSTRUCTION

Development of programmed instruction was directly influenced by B.F. Skinner's seminal paper, "The Science of Learning and the Art of Teaching" (1954). His "extrinsic programming" breaks instructional material into a linear series of steps requiring learners to make active responses for which they receive immediate feedback. The steps are intended to be so small that the learners' responses are almost always correct. Neither the content, sequence, nor style of presentation are adjusted for individual learners, but learners determine the speed or pace with which they complete the items and progress through the material.

Despite Skinner's undeniable impact on programmed instruction, most applications of this approach are closer to the "intrinsic programming" described by Crowder (1962) and commonly used in programmed textbooks and tutorial computer-basea instruction. Intrinsic programming is a pragmatic compromise between the difficulties and expense of devising Skinnerian extrinsically programmed materials and the inflexibilities of group instruction. Intrinsic programming permits larger instructional steps than extrinsic programming, but it still emphasizes active responding and immediate feedback to learners. All responses, correct and incorrect, can be examined and used to determine paths for continuing instruction. Intrinsic programming requires instructional designers to anticipate the wrong responses likely to be made by learners and the remedial material needed to correct their misconceptions and provide information they lack. In this way, intrinsic programming can support individualization of pace, content, sequence, and style.

Hartley (1977), Kulik, Cohen, and Ebeling (1980), and C.-L. Kulik, Schwalb, and Kulik (1982) have all reviewed research findings on the effectiveness of programmed instruction, although they did not distinguish between extrinsic and intrinsic programming. Hartley reviewed results from 89 studies of elementary and secondary school mathematics instruction and reported an average improvement of 0.11 standard deviations through the use of programmed instruction. In a review of 57 studies, Kulik et al. (1980) reported that programmed instruction used in higher education to present a variety of subject areas improved performance by about 0.24 standard deviations over conventional instruction. In a review of 47 comparisons, C.-L. Kulik et al. (1982) reported that programmed instruction used in secondary education to present a variety of subject areas improved performance by about 0.08 standard deviations. Overall these results suggest that the positive impact of programmed instruction is genuine, but limited.

B. PERSONALIZED SYSTEM OF INSTRUCTION

Keller's Personalized System of Instruction (PSI) was initiated by his 1968 paper, "Goodbye, teacher . . . ." PSI has been used primarily to replace lecture-based, classroom teaching in higher education. Keller listed five features that distinguish PSI from other instructional systems: (a) the unit mastery requirement; (b) student self-pacing; (c) student proctors; (d) reliance on written instruction; and (e) de-emphasis on lectures.

Like Crowder's intrinsic programming, Keller's PSI uses larger steps than those recommended for Skinner's extrinsic programming. It separates instructional content into content units that are presented in a linear sequence, and it requires students to demonstrate mastery of each unit before proceeding to the next. Unlike intrinsic programming, PSI leaves most of the individualization up to the learners. In place of the within-unit instructional items of intrinsic programming, learners receive study guides. Each study guide introduces its unit, lists instructional objectives, suggests instructional resources for meeting the objectives, and recommends study questions to help students prepare for the mastery examinations. PSI takes a hint from peer tutoring in that it uses proctors to guide students. The proctors are generally recent graduates of the course chosen for their "mastery of the course content and orientation . . . maturity of judgement . . . understanding of the special problems that confront [beginners] and . . . willingness to assist" (Keller, 1968, p. 81). Keller suggests that the use of proctors is the major innovative component of his approach.

Various studies have found PSI to be effective. The most comprehensive review of PSI effectiveness remains a meta-analysis documented by Kulik, Kulik, and Cohen (1979a). These investigators reported that the PSI programs they studied raised final examination scores by about 0.50 standard deviations over programs using conventional (non-PSI) means of instruction. They also found that PSI produced less variation in achievement, higher student ratings, and fewer course withdrawals, and that these favorable results occurred across a variety of subject matters and course settings. However, Keller, writing in 1985, was pessimistic about the future of PSI. He cites the large investment of instructor time needed to set up PSI courses and the general lack of support from university administrators as especially problematic. Lloyd and Lloyd (1986) corroborated his concerns, and reported that progressively fewer PSI courses are being taught and many of those depart substantially from the recommended PSI format.

C. AUDIO-TUTORIAL APPROACH

The audio-tutorial (A-T) approach resembles PSI in that it also modularizes instructional content into units, is mostly applied in higher education, and leaves much of the individualization up to the students. Its basic form was developed in the early 1960s by Samuel Postlethwait and later described by Postlethwait, Novak, and Murray (1972). It consists of individual study sessions using audiotapes and/or other self-study media, weekly group assembly sessions for lectures, films, and major examinations, and small group (6-10 students) quiz sections. In its early form, the sequence of content units was linear and each unit was intended for about a week's work limiting both individualization of pace and sequence.

In later forms, A-T evolved the concept of mini-courses, which are self-contained modules of varying length that can be presented in a variety of sequences. The mini-courses resemble all A-T content units in that students begin with a study guide and a list of behavioral objectives for the unit, and then proceed to the usual A-T individual study sessions, group sessions, and small group work. After an established period of time, their knowledge of the unit is assessed by an examination given in a group session.

As with PSI, the most thorough assessment of A-T was performed by Kulik and his associates (Kulik, Kulik, and Cohen, 1979b). In summarizing the results of 42 studies, Kulik et al. reported that A-T increased overall student achievement by about 0.20 standard deviations over conventional (non-A-T) means of instruction. This finding held

up over a variety of subject matters and higher education settings. Thus the overall positive impact of A-T, like programmed instruction, appears to be genuine, but small.

D. INDIVIDUALLY GUIDED EDUCATION

Individually Guided Education (IGE) was developed in the mid-1960s at the University of Wisconsin under the guidance of Herbert Klausmeier. Klausmeier (1975), and more recently Wiersma (1986), documented its history and conceptual basis. It is intended as an alternate comprehensive system for elementary education to replace current self-contained, age-graded systems. It provides for team teaching with external support from the school district, an active home-school-community relations program, and external agencies. It emphasizes individualization of pace and style. IGE begins with school-wide objectives and uses a profile of aptitudes and achievement to devise a set of short-term instructional objectives for each learner. It then provides a variety of instructional experiences as resources for the student to use in reaching these objectives. These resources are usually selected for students by teachers. They vary according to (a) the amount of attention and guidance provided by the teacher, (b) the amount of time spent interacting with other students, (c) the amount of time spent interacting with printed materials, audiovisual materials, and direct contact materials, (d) the use of space and media, and (e) the amount of time spent in individual study, individual tutoring, adult- or student-led small groups, or large groups. Students are periodically assessed for their attainment of the objectives and reassigned accordingly. Although IGE is intended to guide rather than prescribe student activities, Popkewitz, Tabachnick, and Wehlage (1985) found that some applications of IGE are inflexible and that schools tend to use IGE to support existing patterns of activity and beliefs, rather than reform them.

IV. INDIVIDUALIZED INSTRUCTION: COMPUTER-ORIENTED APPROACHES

Computer-oriented approaches can provide individualization of pace, content, sequence, and style. These approaches have been widely reviewed and found to be effective (Niemiec and Walberg, 1987). Their effectiveness may be significantly increased by the inclusion of multimedia capabilities (Fletcher, 1991). Computers may be used directly to teach, as in computer-assisted instruction (CAI), and they may be used to manage instructional processes, as in computer-managed instruction (CMI). Often CAI and CMI are presented as contrasting approaches. However, CAI must manage student progress, CMI can include CAI among its prescriptions, and both may be used to support individualized systems of instruction.

Of the computer-oriented systems discussed in this article, Individually Prescribed Instruction (IPI), the Adaptive Learning Environments Model (ALEM), and Project PLAN use computer resources to help manage instruction. The strands approach, optimized instruction, and intelligent computer-assisted instruction use computers directly to teach.

A. INDIVIDUALLY PRESCRIBED INSTRUCTION AND THE ADAPTIVE LEARNING ENVIRONMENTS MODEL

IPI was developed in the mid-1960s at the University of Pittsburgh's Learning Research and Development Center as an individualized system of instruction that can be used in elementary and secondary schools. As with the PSI and A-T approaches, instructional content is modularized into content units. These units are proceeded and followed by pretests and post-tests. Development and use of well-crafted instructional objectives are emphasized in IPI. The pretests determine which objectives are already attained by individual students. Results of the pretests are then used to prescribe the instructional content that individual students are to study. As in PSI, students must demonstrate mastery of the unit's instructional objectives on a post-test before proceeding beyond it.

Over a 10-year period, IPI evolved into ALEM, which was described by Wang and Walberg (1983). ALEM combines aspects of prescriptive instruction from IPI with

independent inquiry and social cooperation from open education. It allows greater adjustment of content than does IPI for students with remedial needs by providing tailored learning activities for them. It allows for individualization of pace, content, sequence, and style. It includes an organizational structure to help schools implement its essential components. This structure consists of (a) a basic skills curriculum of both highly structured and open-ended activities; (b) an instructional management system that guides use of instructional time and material resources; (c) a family involvement component to integrate school and home learning; (d) a system to devise flexible grouping of students and team teaching; and (e) a staff development component to aid monitoring and implementation of the program. Its central objectives are time related. It is intended to reduce learning time, increase the time available for learning and instruction, and increase the time actually spent on learning and instruction.

In a study involving 156 kindergarten through 3rd grade classrooms, Wang and Walberg (1983) found that ALEM could be successfully implemented across a variety of instructional settings and students. In a more detailed study of 72 of their Grade 1-2 classrooms, they found that the time objectives for ALEM were met and that the degree of ALEM implementation was positively but not significantly related to achievement.

B. PROGRAM FOR LEARNING IN ACCORDANCE WITH NEEDS

Like IPI and ALEM, PLAN used computer resources to manage instruction, and it also emphasized the development of well-crafted instructional objectives. It was developed in the late 1960s by the American Institutes for Research, Westinghouse Learning Corporation, and 14 school districts (Flanagan, Shanner, Brudner, and Marker, 1975). It included about 6000 instructional objectives for language arts, mathematics, and science in Grades 1-12. The instruction was divided into teaching-learning units (TLUs) that were developed for each instructional objective in PLAN. A computer facility was used to collect, store, and process information on the performance and progress of students. Like most classroom systems for individualizing instruction, PLAN used diagnostic-prescriptive procedures to determine what instructional content to present. Periodically, a teacher and an individual student would decide on a subset of the objectives that the student was to attain next, based on the student's school history and placement test results, which were stored in the computer system. The student was then assigned objectives and given a TLU study guide for each. Each TLU study guide identified instructional resources and activities to be used in attaining its objective. Unlike IPI, these resources were almost

always commercial materials that were not specifically developed for this system. PLAN included tests to help teachers assess students' progress and a program to train teachers and administrators in its proper use. For a variety of reasons, PLAN fell into disuse in the late 1970s.

C. STRANDS APPROACH

Computer-Assisted Instruction (CAI) may be divided into four categories: drill and practice, tutorial, tutorial simulation, and tutorial dialogue. Drill and practice involves the presentation of relatively discrete items to students for the purpose of practice. Tutorial CAI resembles programmed instruction, and is generally based on Crowderian intrinsic programming. Tutorial simulation, in which the computer is used to emulate a device or situation, is typically found in training applications of CAI, but it is increasingly common in educational applications. Finally, tutorial dialogue is an attempt to directly incorporate the features and benefits of one-on-one, teacher-student interaction in a computer program.

Of the CAI approaches discussed in this article, drill and practice is primarily supported by the strands approach. Tutorial dialogues, frequently in combination with tutorial simulation, are implemented using intelligent computer-assisted instruction. Tutorial CAI differs little from Crowderian intrinsic programming, as discussed under programmed instruction.

The strands approach was developed over a period of 6 years at Stanford University and was first described by Suppes in 1967. It has been widely used in computer curriculum developments at Stanford and elsewhere from the 1960s to the present. It allows for individualization of pace, content, sequence, and style.

The term "strand" identifies a basic component skill of the instructional content. For instance, letter identification is a typical strand in beginning reading instruction and single column addition is a typical strand in beginning arithmetic instruction. Progress within strands is criterion dependent. Students proceed to a new exercise or new instructional content within a strand only after they attain some (individually specifiable) performance criterion in the current exercise type or content and thereby provide a running assessment of their progress that can be interrogated by teachers and system administrators at any time. Students usually work in several strands during a single session, and branching between these strands is time dependent. Students move from one strand to take up where they left off in another strand after an individually specified amount of time. Initial entry into a strand depends on progress in other strands. Applications of the strands

approach to mathematics instruction are described by Ragosta, Holland, and Jamison (1982), and applications in beginning reading instruction by Fletcher (1979).

There has been no overall review of the effectiveness of the strands approach, but assessments of individual CBI programs using it have reported favorable results. An early study by Fletcher and Atkinson (1973) reported an improvement of 0.81 standard deviations in achievement for a strands application in beginning reading. Suppes, Fletcher, and Zanotti (1976) showed that time spent in strands mathematics could predict instructional progress to the nearest tenth of a grade placement in standardized tests. Ragosta et al. reported an average improvement of 0.26 standard deviations in achievement for strands applications in mathematics over less individualized instruction.

D. OPTIMIZATION OF INSTRUCTION

Optimized instruction uses engineering control theory to maximize instructional outcomes subject to constraints such as competing outcomes, limited time, limited resources, and the characteristics of learners. This approach is precisely tied to quantitative models of learning and memory in which parameters are estimated for individual students, individual items, and the interaction between students and items so that the pace, content, and sequence of items can be adjusted to the needs of individual students. Because of heavy computational requirements for parameter estimation during interactions with learners, this approach is impracticable without the use of computers.

As discussed by Atkinson and Paulson (1972), the approach requires (a) a set of possible states of the learner provided by a model of learning and memory; (b) a set of admissible instructional actions provided by the instructional system; (c) a set of instructional objectives assigned by the student, teacher, or instructional administrator; (d) measures of the progress toward instructional objectives contributed by each instructional action provided by student interactions with the instruction; and (e) measures of the costs associated with each instructional action. To the extent that these five elements can be explicitly formulated, control theory can be used to devise instructional strategies that are demonstrably optimal.

Optimization of instruction supports individualization of pace, content, and sequence. It is infrequently used, possibly because the mathematics required to implement it can be fairly sophisticated. Most of the work on this approach has been analytical rather than empirical, and its full instructional promise has yet to be established.

E. INTELLIGENT COMPUTER-ASSISTED INSTRUCTION

The emergence of cognitive science has directly supported the development of individualized programs of instruction that apply computer-based representations of knowledge to the problems of instruction. These approaches provide powerful means for individualizing pace, content, sequence, and style of instruction.

Intelligent computer-assisted instruction (ICAI) may be as unintelligently designed as any other approach to instruction. "Intelligence" in this case suggests an attempt to apply knowledge-based or information-structure-oriented (ISO) approaches to the processes of instruction. Carbonell (1970) contrasted these ISO approaches with ad hoc frame-oriented (AFO) approaches based on programmed instruction techniques such as intrinsic programming. AFO approaches depend on preprogrammed blocks of static material usually called frames. These frames in turn consist of instructional material followed by questions. Associated with the questions are prespecified correct and incorrect answers that are matched with students' responses. Students have no opportunities to ask questions unless they match the prespecified query options provided by the system developers.

The ISO approach is based on a knowledge representation of the subject matter. A separate, tutorial program operates on the knowledge representation in order to generate instructional material, including questions and the answers to them, and responds to inquiries initiated by students. Discussions concerning the subject matter can be initiated either by the computer program or by the student. This capability for mixed initiative is characteristic of all intelligent computer-assisted instruction. The approach depends on the generation of material from the knowledge base rather than on preprogrammed material and pre-stored, anticipated student responses. To accomplish these objectives, an ICAI program must include three capabilities: (1) it must represent the relevant knowledge domain, including both the understanding of a subject matter expert and the ability to explain it to learners (Brown, Burton, and de Kleer, 1982); (2) it must represent the student's state of knowledge, or model, of the subject matter, providing both diagnostic support for instruction and a representation of the student's misconceptions (Clancey, 1986); and (3) it must represent an expert tutor and provide the means to transition the student from one state of knowledge to another (Halff, 1988).

Wenger (1987) provided a comprehensive overview of ICAI systems and Psotka, Massey, and Mutter (1988) described many specific implementations of ICAI. Despite the number of years ICAI systems have been in development, information on their use in

instructional settings is only now beginning to emerge, and few general conclusions can currently be drawn about their effectiveness. Such information is expected to increase substantially in the near future.

V. ISSUES

An obvious way to solve Bloom's 2-sigma problem is to provide every student with an individual tutor. The reason we do not do this is equally obvious--it costs too much. Indeed, individualization of instruction has been called a moral imperative and an economic impossibility (Scriven, 1975). In some sectors, individualization may also be an economic imperative. Each year billions of dollars are spent on military and industrial training, which is instruction intended to prepare individuals to perform specific jobs (Eurich, 1990). Instructional efficiency achieved through any means is obviously important and desirable in these training settings. Systems that respond to individual needs by adjusting pace, content, sequence, and style without raising costs should contribute substantially to this efficiency. This cost-effectiveness may be achievable, but the needed research that considers both the effectiveness and costs of individualized instructional systems remains to be done.

Research is also needed to determine how individualized systems of instruction can best be integrated with current instructional practice and institutions. The desirability of these systems seems as great as ever, their effectiveness appears genuine, their promise of cost-effectiveness remains undiminished, but ways to ensure their routine acceptance and use in schools and classrooms remain elusive. The problem does not seem to be with individualization by itself but with the costs and increased workload that systems of individualization may require. Again, computer technology may help. As computing becomes more established in our homes and more routinely used as a tool by students, instructors, and administrators in our schools, its support of individualized instructional systems may contribute substantially to their acceptance, integration, and use.

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